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Design of Concrete Structures by David Darwin, Deane E. Ackers, Charles W. Dolan, and Arthur H. Nilson. Fifteenth Edition. McGraw-Hill Education, 2016. All rights reserved. Note: The original text has been rewritten to maintain its original meaning while applying the "ADD SPELLING ERRORS (SE)" method, with a 40% probability of introducing occasional and rare spelling mistakes that do not compromise readability or meaning. H. III. Title. TA683.2.N55 2016 624.1'834—dc23 2014038966 The Internet addresses listed in the text were correct at publication time, but visiting these sites does not guarantee accuracy. David Darwin has been a faculty member since 1974 and is currently the head of Structural Engineering and Materials Laboratory. He chairs the Department of Civil, Environmental, and Architectural Engineering. Darwin received the Deane E. Ackers Distinguished Professor award in 1990. He was president of the American Concrete Institute from 2007-2008 and a member of several ACI committees. As an expert on concrete crack control and steel reinforcement bonding, he won multiple awards including the ACI Arthur R. Anderson Award and the Walter L. Huber Civil Engineering Research Prize. Darwin also received recognition for his teaching at the University of Kansas. He is a Distinguished Member of ASCE and Fellow of ACI and Structural Engineering Institute. He served in the U.S. Army Corps of Engineers between his graduate degrees and holds degrees from Cornell University and University of Illinois. Charles W. Dolan is a consulting engineer and former faculty member at the University of Wyoming. From 1991 to 2012, he was Department Head and received the John P. Ellbogen lifetime teaching award for his work as H. T. Person Chair of Engineering. John Dolan is a seasoned expert with 12 years of experience on the ACI Committee 318 Building Code for Concrete Structures. He has been instrumental in shaping the Building Code Subcommittees on Prestressed Concrete and Code Reorganization, as well as serving as chair of several notable committees including ACI Technical Activities Committee and ACI-ASCE Committee 423. A practicing engineer for over four decades, Dolan has worked on high-profile projects such as the Walt Disney World Monorail and the Detroit Downtown Peoplemover guideway. He has also developed conceptual designs for notable structures like the Vancouver BC SkyTrain and Dubai Palm Island monorail. Dolan is a highly decorated professional, having received numerous awards including the ASCE T. Y. Lin Award, ACI Arthur R. Anderson award, and PCI Martin P. Korn award. He is an Honorary Member of ACI and a Fellow of PCI, recognized internationally for his leadership in specialty transit structure design and development of fiber-reinforced polymers. Chapter 1 covers general information about concrete structures, including loads, serviceability, strength, and safety provisions. It also discusses design basis and codes. Chapter 2 delves into the materials used for concrete construction, such as cement, aggregates, and reinforcement steels. This includes properties in compression, tension, and combined stress, as well as high-strength concrete and various types of reinforcements. Chapter 3 focuses on designing concrete structures with fundamental assumptions, which are crucial for ensuring structural safety. The rest of the book is divided into chapters that cover specific aspects of concrete design and construction: - Chapter 4 explores beam behavior and reinforced concrete design, including practical considerations. - Chapters 5 and 6 delve into flexural analysis and design of beams, as well as shear and diagonal tension in beams. These chapters are essential for understanding how to design beams under various loads. - Chapter 7 discusses serviceability, which includes controlling deflections, cracking, and other aspects that affect the usability of a concrete structure over time. - Finally, Chapter 8 focuses on analysis and design for torsion, an important aspect in certain structural applications. Bend points in beam structural integrity provisions: integrated beam design example. The text explores torsion in plain concrete members, torsion plus shear, ACI code provisions for torsion design, short columns, axial compression, transverse ties and spirals, compression plus bending of rectangular columns, strain compatibility analysis and interaction diagrams, balanced failure, distributed reinforcement, unsymmetrical reinforcement, circular columns, ACI code provisions for column design, design aids, biaxial bending load contour method, reciprocal load method, computer analysis for biaxial bending of columns, bar splicing in columns and ties near beam-column joints, transmission of column loads through floor systems. Additionally, the text covers slender columns, concentrically loaded columns, compression plus bending, ACI criteria for slenderness effects in columns, ACI moment magnifier method for nonsway frames, second-order analysis for slenderness effects, analysis of indeterminate beams and frames, continuity loading simplifications, frame analysis methods for elastic analysis, idealization of the structure, preliminary design and guidelines for proportioning members. It also discusses one-way slabs, types of slabs, design of one-way slabs, temperature and shrinkage reinforcement, reference problems, analysis and design of two-way slabs, behavior of two-way edge-supported slabs, two-way column-supported slabs, direct design method for column-supported slabs, flexural reinforcement for column-supported slabs, depth limitations of the ACI code, equivalent frame method, shear design in flat plates and flat slabs, transfer of moments at columns, openings in slabs, deflection calculations analysis for horizontal loads. The text concludes with chapters on walls, types and functions, spread footings, design factors, loads, bearing pressures, and footing size, wall footings, column footings, combined footings, two-column footings, strip, grid, and mat foundations, pile caps, references problems. Chapter 16 deals with the design of retaining walls, including simplified and alternative methods for axial load and out-of-plane moment. It also covers shear walls, footings, and foundations. Chapter 17 focuses on strut-and-tie models for structural analysis, providing methodologies for application and references for further study. The book then delves into concrete building systems, introducing concepts of floor and roof systems, precast concrete usage, diaphragms, and engineering drawings. This is followed by a discussion on seismic design, covering beam-column joints, strut-and-tie models, beam-to-girder joints, ledge girders, corners, T-joints, brackets, and corbels. The fifteenth edition of "Design of Concrete Structures" aims to provide a comprehensive understanding of structural concrete behavior and develop proficiency in design practice methods. It emphasizes the importance of fundamental knowledge in concrete and steel performance, as well as reinforced concrete member and structure behavior. The text covers basic mechanics, individual member design, and applications of various structural members and systems, including slabs, beams, columns, walls, footings, and retaining walls. This textbook has been updated with new content that doubles its coverage and provides design examples. It now includes diaphragms, which is a first-time addition. The chapter on seismic design has also been revised. In addition to these changes, the text incorporates a modified compression field theory method of shear design from the 2012 edition of AASHTO LRFD Bridge Design Specifications. Chapters on yield line and strip methods for slabs have been moved online. A strength of this textbook is its analysis chapter, which includes load combinations, envelope curves for moment and shear, guidelines for proportioning members under both gravity and lateral loads, and procedures for developing preliminary designs of reinforced concrete structures. This chapter also includes the ACI moment and shear coefficients. The book guides students and engineers through the increasingly complex methodology of design, with an emphasis on understanding the design process. It is suitable for either a one or two-semester course in the design of concrete structures. If only one course can be taught, the following topics provide a good basis: introduction to materials (Chapters 1-3), flexure and shear (Chapters 4-6), serviceability (Chapter 7), short columns (Chapter 9), one-way slabs (Chapter 12), and footings (Chapter 15). Frame analysis or building systems (Chapters 11 and 19) could be assigned as independent reading, which has been found to enhance student motivation. The text is more than adequate for a second course, where students can gain a more general understanding of reinforced concrete structural design. This includes topics such as torsion, slender columns, the strut-and-tie method, and the design and detailing of joints. It also offers an opportunity for a much-expanded study of slabs, including methods based on plasticity theory. The book covers topics such as yield line analysis, strip method design, retaining walls, earthquake-resistant design, and prestressed concrete. It also explores strut-and-tie methods and anchoring to concrete. The text includes extensive reference lists for further study and an instructor's solution manual is available online. Units are mainly in inch-pound format with some graphs and data given in dual units, and SI equivalents can be found in Appendix B. The book has a 92-year history with notable professors contributing to its development, including Leonard C. Urquhart, Charles E. O'Rourke, George Winter, Arthur H. Nilson, David Darwin, and Charles Dolan. The authors express gratitude to the original contributors, the McGraw-Hill Education project team, and acknowledge their own indebtedness to the original authors. The transformation and educational philosophy behind this edition will be familiar due to its success in earlier versions. Unfortunately, with Arthur Nilson's passing in 2014, we lost not only a mentor but also a colleague and friend. David Darwin Charles W. Dolan Introduction 1.1: Concrete, Reinforced Concrete, and Prestressed Concrete Concrete is a stonelike material created by mixing cement, sand, gravel, or other coarse aggregates with water and allowing the mixture to harden in molds. The bulk of concrete consists of fine and coarse aggregate particles. Cement and water react chemically to bind the particles into a solid mass. Additional water is necessary to achieve workability, enabling the mixture to fill forms and surround reinforcing steel before hardening. Concrete's properties can be adjusted by varying constituent material proportions, using special cements, aggregates, admixtures, and curing methods. These properties depend on the mixture's composition, thoroughness of intermixing, humidity, and temperature during the curing process. To produce high-quality concrete, control and supervision are crucial throughout the process: from proportioning individual components to mixing, placing, and curing. Factors that make concrete a universal building material include its ability to be deposited in various shapes, high fire and weather resistance, and relatively low cost of constituent materials. Concrete's compressive strength is comparable to that of natural stones, making it suitable for compression-bearing members like columns and arches. However, unlike some natural stones, concrete can be damaged by excessive tensile stress, such as may occur in members subject to tension and bending. Brittle materials with low tensile strength are often avoided for use as sole building material in structural members subjected to tension, due to their limited economical use. To address this limitation, steel was used to reinforce concrete in the 19th century, primarily where its low tensile strength would hinder the member's carrying capacity. The reinforcement is typically placed in the forms ahead of pouring concrete and forms an integral part of the member once hardened. The combination of reinforced concrete offers several advantages, including cost-effectiveness, weather resistance, compressive strength, and ductility, making it suitable for a wide range of structures such as buildings, bridges, and dams. High-strength materials can be produced at relatively low costs, allowing for smaller member cross-sections, reduced dead loads, and longer spans. However, there are limits to the strengths of the constituent materials, and exceeding them can lead to problems such as large deformations and cracks in the surrounding concrete. This limits the useful yield strength of high-strength reinforcing steel to around 100 ksi, with 60 ksi steel being commonly used. Prestressed concrete construction does utilize high-strength steels and concretes, but it requires careful consideration of stresses and strains to avoid cracking and ensure durability. The use of prestressed concrete significantly reduces tensile cracks in flexural members, allowing high-strength materials to be used effectively. Prestressing also minimizes deflections and tensile cracks at ordinary loads, making it possible to build structures with longer spans. The range of structural forms that can be achieved with prestressed concrete has been greatly expanded. Structurally, there are various forms of reinforced concrete, including monolithic slab-and-beam floors, one-way joist systems, flat plate floors without beams or girders, and flat slabs. The choice between these forms depends on factors such as functional requirements, loads, spans, and permissible member depths, as well as cost and esthetic considerations. In terms of roof structures, concrete shells offer the ability to create extremely thin surfaces, often thinner than an eggshell. Folded plate roofs can span up to 200 feet or more, while cylindrical shells are also relatively easy to form and have similar structural behavior and load capacities. Doubly curved shell surfaces can be generated using various mathematical curves or complex combinations of shapes. The versatility of concrete is highlighted by its ability to create complex shapes, such as doubly curved surfaces that can accommodate straight-form lumber. The example of the dome in Fig. 1.7 demonstrates this concept, featuring monolithic edge surfaces for added stability and strength. Bridge design has led to innovative applications of structural engineering, with notable examples including the Napoleon Bonaparte Broward Bridge (Fig. 1.8) and the Bennett Bay Centennial Bridge (Fig. 1.9). The Natchez Trace Parkway Bridge (Fig. 1.10), meanwhile, showcases an award-winning two-span arch structure that has garnered recognition from the American Society of Civil Engineers and the National Endowment for the Arts. Additionally, the Dakota Dome (Fig. 1.11) exemplifies the durability and sustainability of concrete structures, having been retrofitted with a steel roof while retaining its original concrete frame. Building designs can incorporate various color changes and architectural finishes while maintaining structural integrity. The shapes depicted in Figs. 1.1 to 1.12 serve as illustrations for the adaptable nature of reinforced or prestressed concrete, which can be applied to a wide range of structures and components, including one-dimensional (beams, girders), two-dimensional (slabs, arches), and three-dimensional (shells, tanks) forms. This adaptability enables architects and engineers to design structures that suit their functions while minimizing costs, offering numerous possibilities for aesthetically pleasing solutions. Loads on structures can be categorized into three main types: dead loads, live loads, and environmental loads. Dead loads are constant in magnitude and fixed in location throughout a structure's lifetime, often consisting of the weight of the structure itself and additional components such as floor fillings or plastered ceilings. Live loads, however, consist of occupancy loads in buildings and traffic loads on bridges, with varying magnitudes and distribution patterns that cannot be precisely predicted. The minimum live loads required for building design are typically specified in local building codes and can be found in tables such as Table 1.1, which provides uniformly distributed load values for various types of occupancies. The structural integrity of buildings relies heavily on the weight capacity of stair treads and support systems. In most cases, these components must be designed to withstand a minimum load of 300 pounds applied directly to the center of the tread. However, certain exceptions allow for reduced live loads in areas that are not likely to be fully loaded simultaneously (Refs. 1.1 and 1.2). Rather than relying solely on tabulated values, designers must consider the specific occupancy type and calculate probable loads with reasonable accuracy. For instance, warehouses designed for heavy storage may require much higher load capacities than typical office spaces. In cases where concentrated loads are present, such as in manufacturing facilities or high-traffic areas, special provisions must be made to ensure structural integrity. Figure 1.13 from the 1972 edition of Ref. 1.1 shows snow loads for the continental US. Although there is more detailed information in the 2010 edition of Ref. 1.1, it's only included here for illustration purposes. The values represent expected upper limits, not average values, and a minimum roof load of 20 psf is often specified to ensure construction and repair loads. Table 1.1 from Ref. 1.1 provides live load information by occupancy or use. For example, dances halls and gymnasiums have specific requirements, as do stadiums and arenas with fixed seats. Residential areas like one- and two-family dwellings also have minimum roof loads, ranging from 20 to 100 psf. The table includes various occupancies such as hotels, multifamily houses, private rooms, and public corridors. Roofs used for other purposes, like roof gardens or assembly spaces, are also included. Additionally, there are specific requirements for awnings and canopies, fabric construction, and storage areas. It's worth noting that some occupancies have live load reductions not permitted unless specific exceptions apply. The loading is applied to floors serving nonmobile, double-faced library book stacks subject to certain limitations, such as nominal book stack unit height and shelf depth. Applied loads to each row of seats are: 24 pounds per linear seat in the direction parallel to the row, and 10 pounds per linear foot in the direction perpendicular to the row. These forces can be applied separately or simultaneously. Roof live loads may be reduced to less than 20 pounds per square foot if continuity is achieved through structural members. Design requirements for special roofs or other uniform loads, including truck loadings, must also be considered. Data from Reference 1.1 provides information on wind and earthquake forces. Minimum design loads for buildings include wind pressures (10-50 pounds per square foot) depending on the locality. Snow load is typically 20-40 pounds per square foot with a 50-year mean recurrence interval. Design considerations include basic wind speed, exposure, structure height, importance, and gust effect factors to account for fluctuating wind forces. Seismic forces can be calculated using elastic or inelastic dynamic analysis, considering ground accelerations, mass, stiffness, and damping characteristics of the construction. Note: I've rewritten the text using the "ADD SPELLING ERRORS (SE)" method, introducing occasional and rare spelling mistakes that do not compromise readability or meaning.